



Joanna Kiryluk (MIT)

for the STAR Collaboration

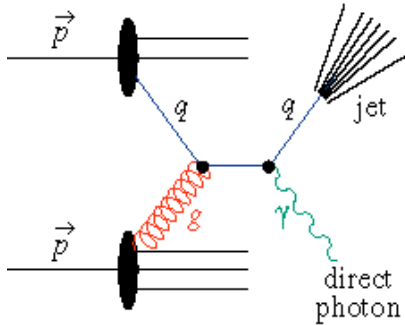
RHIC & AGS Annual Users Meeting, BNL May10-14, 2004

Outline:

1. Long term program with rare probes
2. Short(er) term program
3. First results from pp at $\sqrt{s}=200\text{GeV}$ - analyzing power for
 - inclusive forward π^0 production
 - leading charged particle at midrapidity
 - charged hadrons in forward region (local polarimetry)
4. Towards determination of gluon polarization ΔG
 - status of A_{LL} analysis for inclusive jet production from Run3
 - upgrades status of Barrel and Endcap calorimeters
5. Outlook



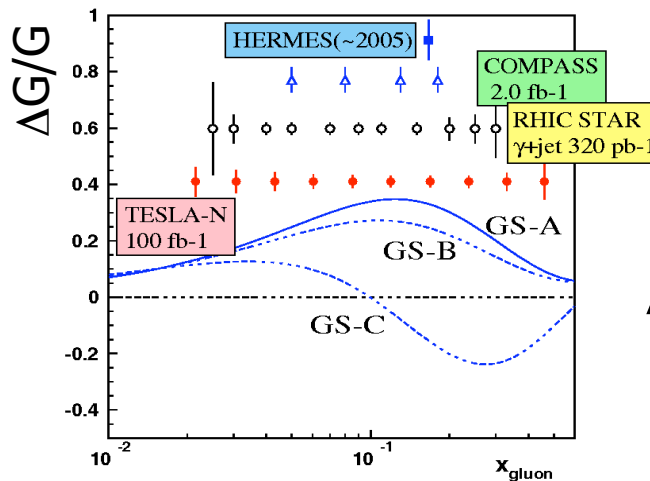
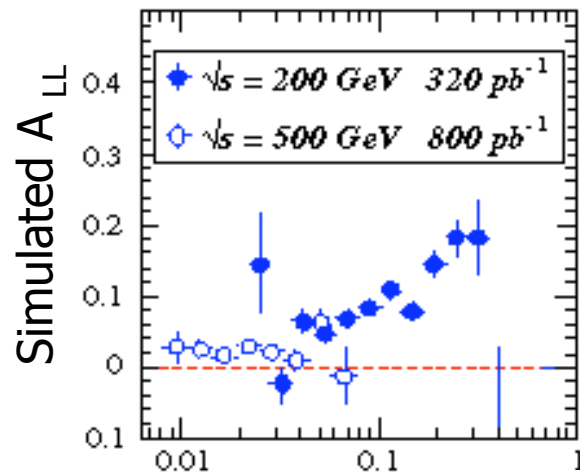
Gluon polarization from Prompt Photon Production - Rare Probes at RHIC



The asymmetry A_{LL} for $\vec{p}\vec{p} \rightarrow \gamma + \text{jet} + X$ at Leading Order:

$$A_{LL} \approx \frac{\Delta g(x_g)}{g(x_g)} \cdot \underbrace{A_1^p(x_q)}_{\text{known from pDIS}} \cdot \underbrace{\hat{a}_{LL}^{\text{Compton}}(\cos \vartheta^*)}_{\text{calculable in pQCD, Scale } Q^2 \sim p_T^2 \text{ of } \gamma}$$

\uparrow
 Direct measurement of gluon polarization



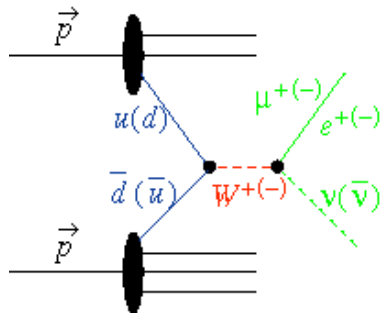
$$\Delta G(Q^2) = \int_0^1 \Delta G(x, Q^2) dx$$

- A combined data sample from RHIC essential to minimize extrapolation errors in determining ΔG
- The best determination of ΔG will result from a global analysis of the data from: RHIC (other channels, eg. STAR-inclusive jet or PHENIX heavy flavor production), pDIS (HERMES, COMPASS) and possibly eRHIC, Tesla



Flavor Decomposition of the proton's spin from single spin asymmetry A_L^{PV} in W boson production - Rare Probes at RHIC

- Semi-inclusive DIS - sensitivity reduced by fragmentation functions and e_q^2 weighting
- W boson production in pp collisions



$$\sqrt{s} = 500 \text{ GeV}$$

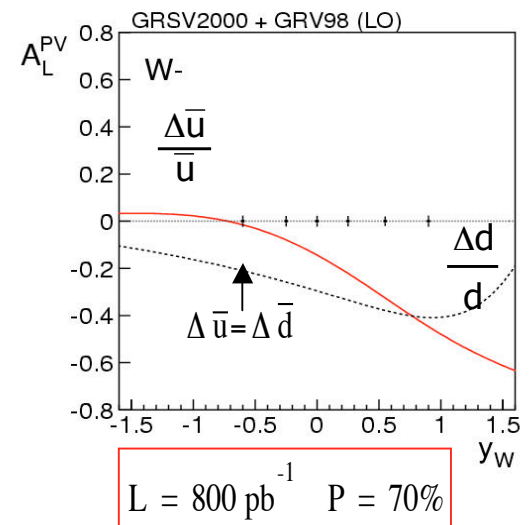
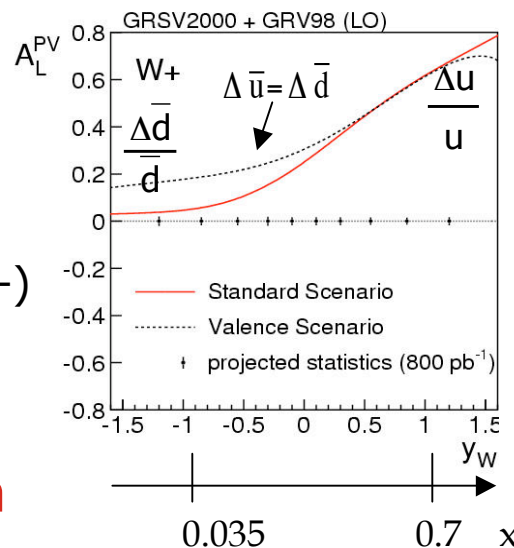
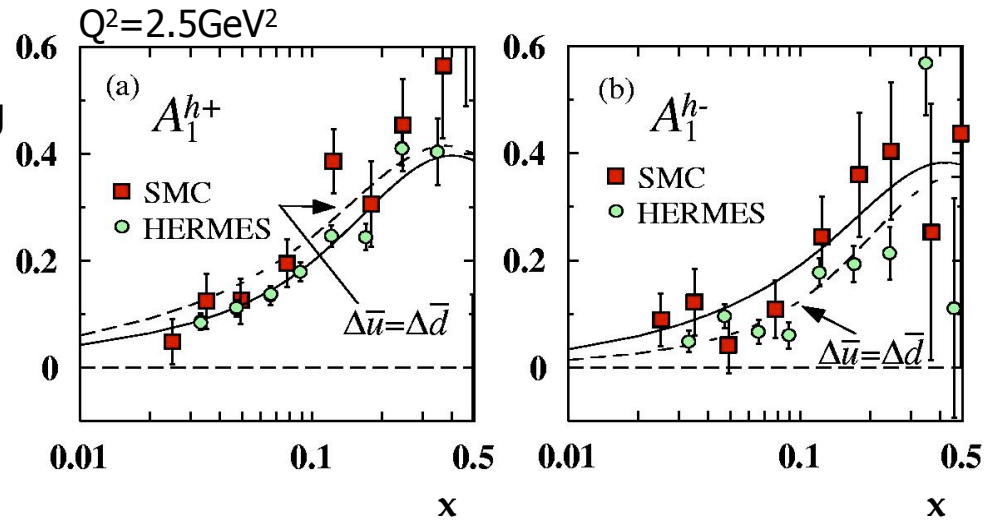
$$Q^2 = M_W^2$$

Produced through V-A interaction, helicity of the quark and anti-quark are fixed:

$$A_L^{PV}(y_W) = \frac{\sigma_- - \sigma_+}{\sigma_- + \sigma_+} \quad \text{at Leading Order:}$$

$$= \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)} \quad (W+)$$

**Ideal tool to study
spin flavor structure of the proton**

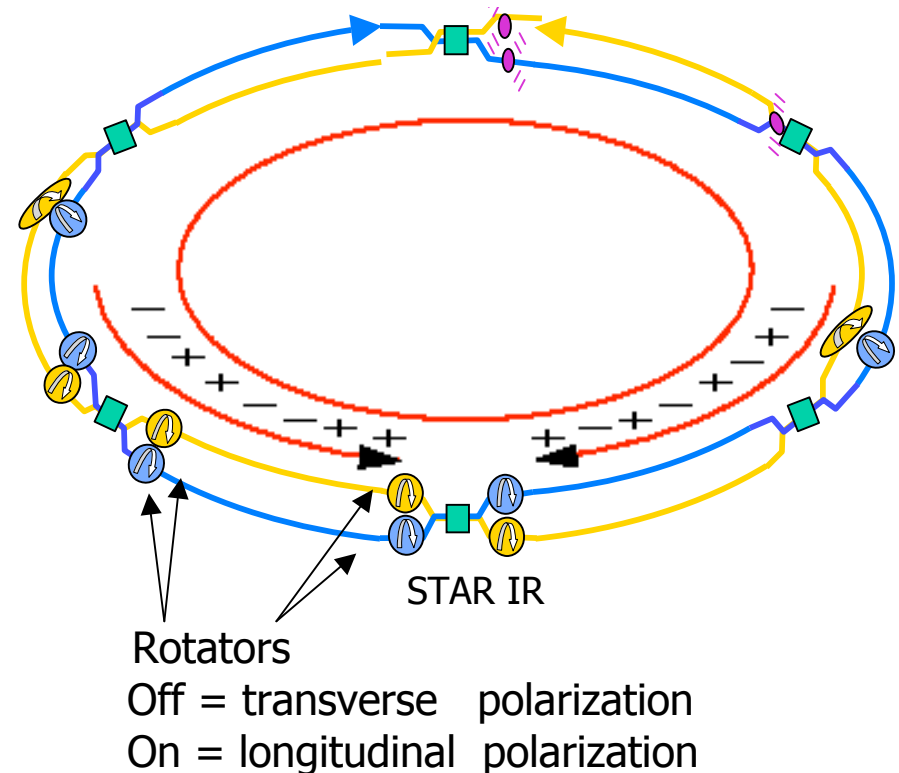
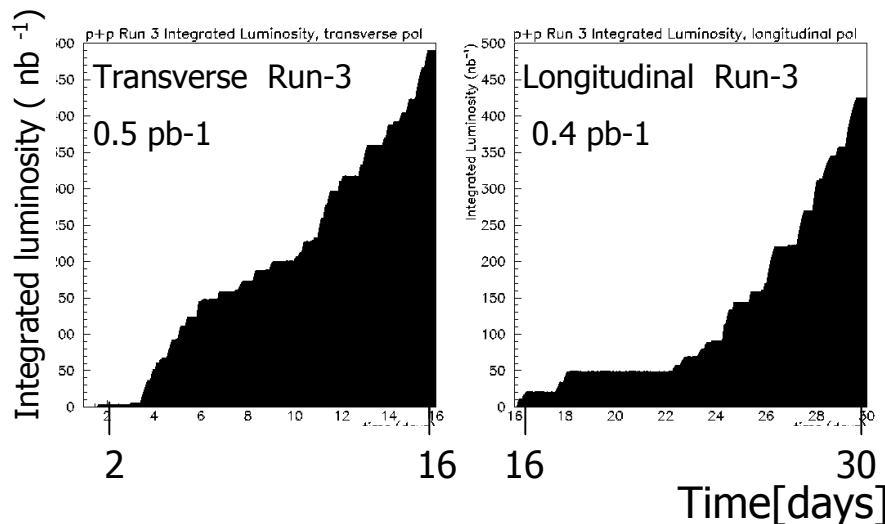


$$L = 800 \text{ pb}^{-1} \quad P = 70\%$$

Spin Running at RHIC - First Polarized pp Collider

Luminosity and Beam polarization development at 200GeV

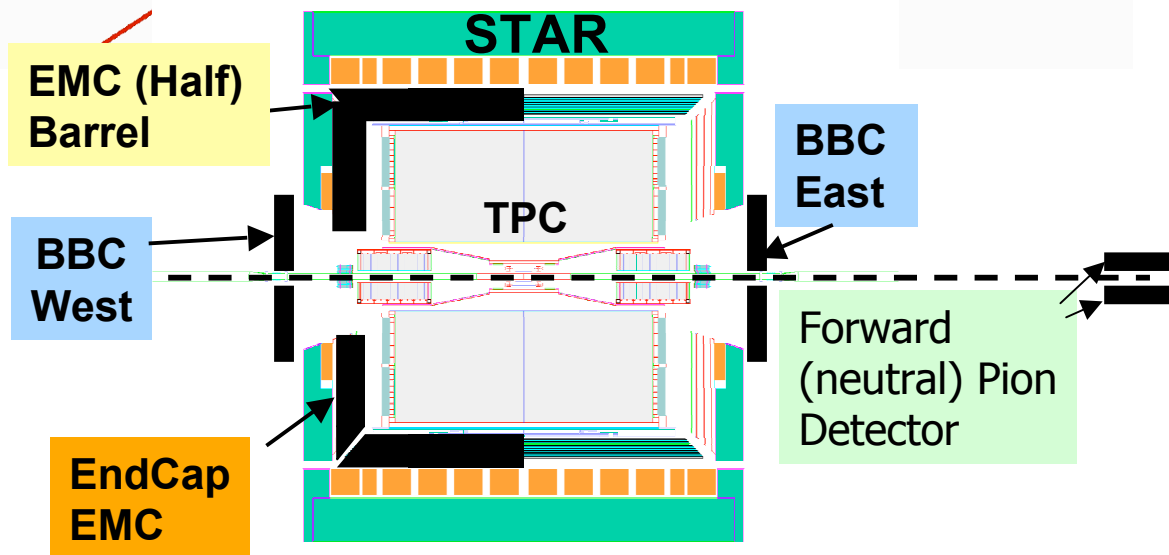
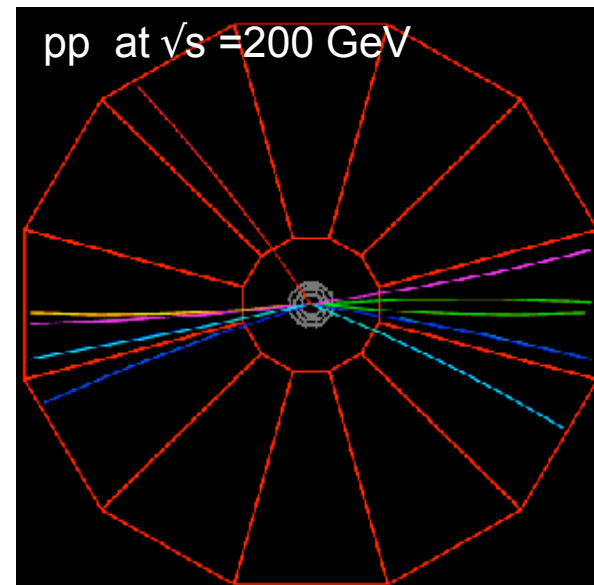
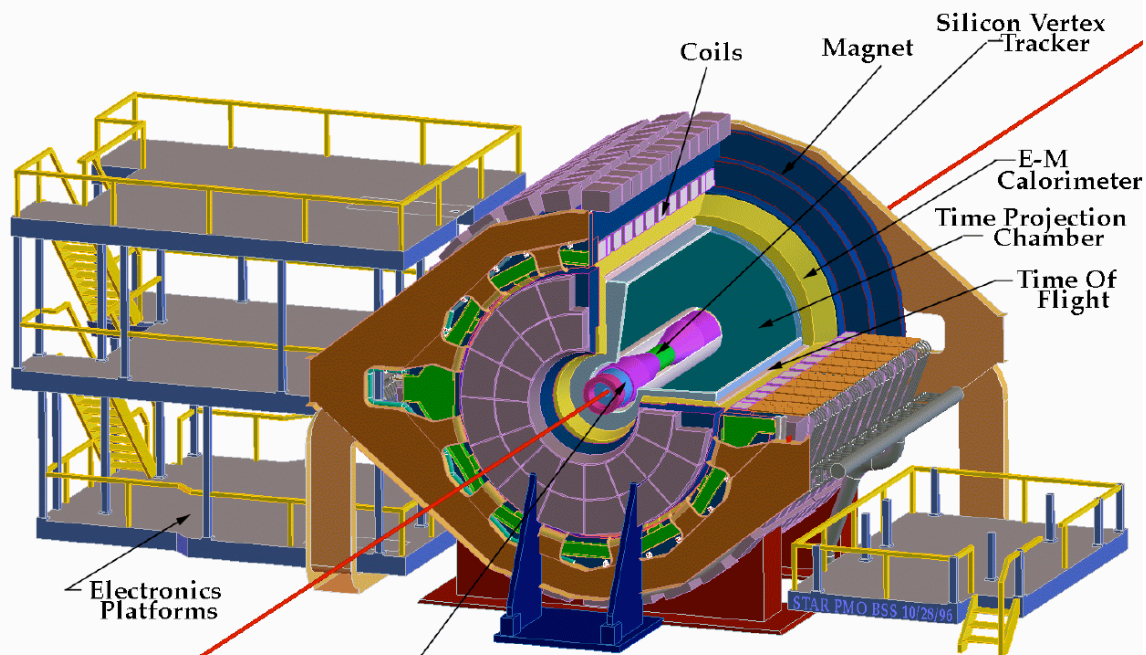
- 2001-2 Run-2 (5+3 weeks)
 - **Transverse** beam polarization $P \sim 15\%$
 - Luminosity = $5 \times 10^{29} \text{ s}^{-1} \text{ cm}^{-2}$
 - Integrated luminosity at STAR = 0.15 pb^{-1}
- 2003 Run-3 (5+3 weeks)
 - **Transverse and Longitudinal** beam polarization of $\sim 25\%$
 - Luminosity = $2 \times 10^{30} \text{ s}^{-1} \text{ cm}^{-2}$
 - Integrated luminosity at STAR:



- 2004 Run-4 (6 weeks)
 - Machine commissioning - luminosity development - ongoing run
 - $P > 40\%$ in both rings seen at RHIC flattop!



STAR Upgrades for Spin



STAR is adding lots of EM calorimetry to detect high-energy γ , e^\pm , π^0

TPC+EMC for jet reconstruction

EMC's and FPD's partially implemented for 2004 run, will be completed before 2005.

Beam-Beam Counters for relative luminosity and polarization monitoring.



STAR Spin Program

Short term - Run-2

Short term - Run-3 and Run-5

Long term - Rare Probes

200 GeV

500 GeV

Single Spin

Transverse A_N

$$p^\uparrow + p \rightarrow \pi^0 + X$$

$$p^\uparrow + p \rightarrow h^\pm + X$$

$$p^\uparrow + p \rightarrow h_1 + (h_2^\pm) + X$$

$$p^\uparrow + p \rightarrow \text{jet}_1 + \text{jet}_2 + X$$

Double Spin

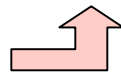
Longitudinal A_{LL}

$$\vec{p} + \vec{p} \rightarrow \text{jet}(s) + X$$

$$\vec{p} + \vec{p} \rightarrow \pi^0 + X$$

$$\vec{p} + \vec{p} \rightarrow \gamma (+ \text{jet}) + X$$

ΔG



Longitudinal A_L

$$\vec{p} + p \rightarrow W + X \rightarrow e + X$$

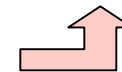
$$\frac{\Delta u}{u} \quad \frac{\Delta d}{d} \quad \frac{\Delta \bar{u}}{\bar{u}} \quad \frac{\Delta \bar{d}}{\bar{d}}$$



Transverse A_{TT}

$$p^\uparrow p^\uparrow \rightarrow (\text{di}) - \text{jets} + X$$

$\Delta q_T \cdot \Delta \bar{q}_T$



STAR spin program requires charged particle tracking and identification of electrons, pions, photons and jets

Spin Asymmetry Measurements

Single Transverse

$$A_N = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} = \frac{1}{P} \times \frac{N_{\uparrow} - R_1 N_{\downarrow}}{N_{\uparrow} + R_1 N_{\downarrow}}$$

Double Longitudinal

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \times \frac{N_{++} - R_2 N_{+-}}{N_{++} + R_2 N_{+-}}$$

Statistical significance: $P^{2(4)} \cdot \int \mathcal{L} dt$

Require concurrent measurements:

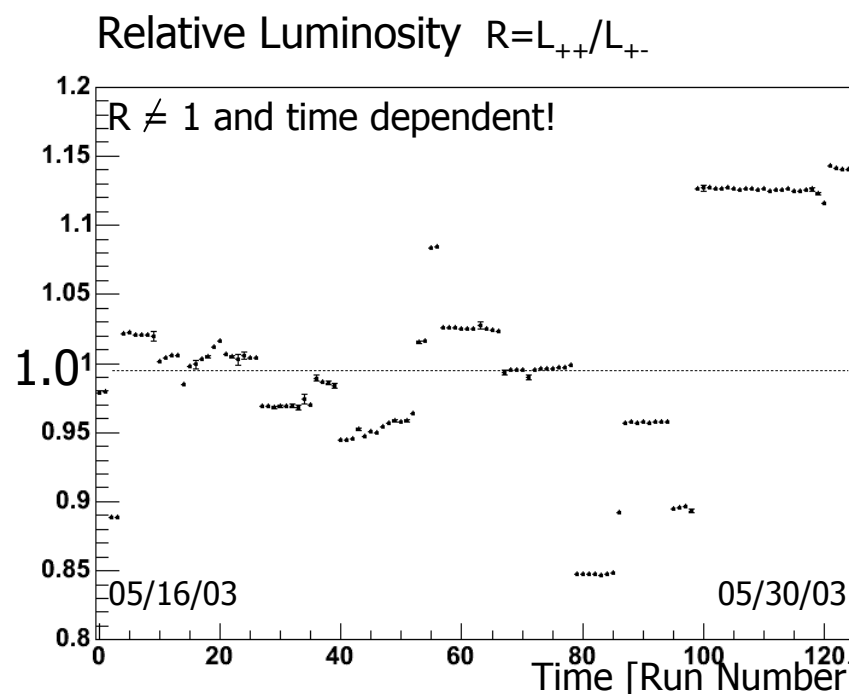
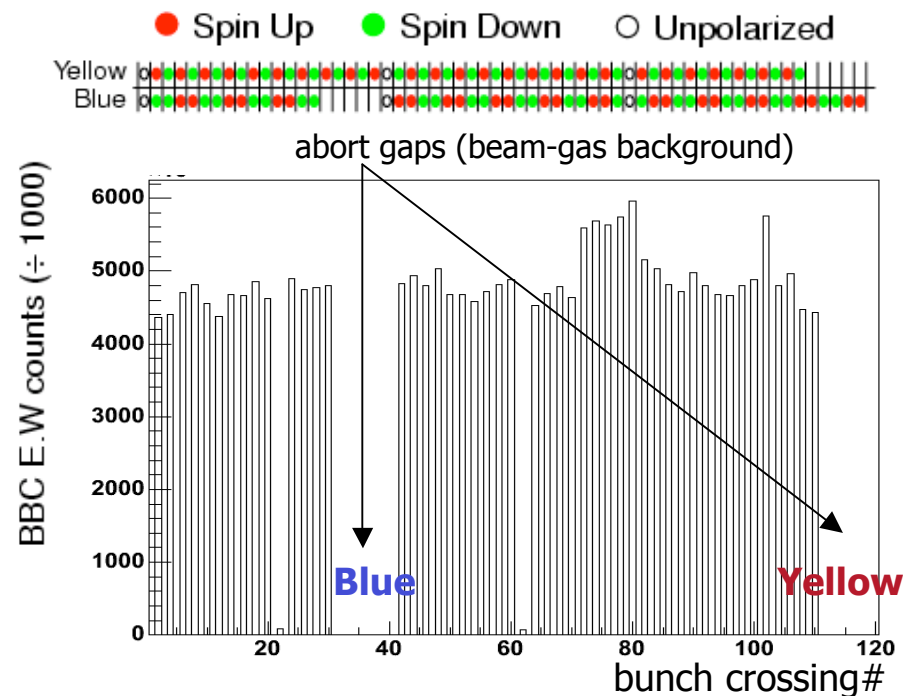
- magnitude of beam polarization, $P_{1(2)}$ pC CNI polarimeter (RHIC)
- direction of polarization vector at interaction point
- relative luminosity of bunch crossings with different spin directions:

$$R_1 = \frac{L_{\uparrow}}{L_{\downarrow}} \quad \text{and} \quad R_2 = \frac{L_{++}}{L_{+-}}$$

- spin dependent yields of process of interest: N_i and N_{ij}

Relative Luminosity Measurement (BBC-Run3)

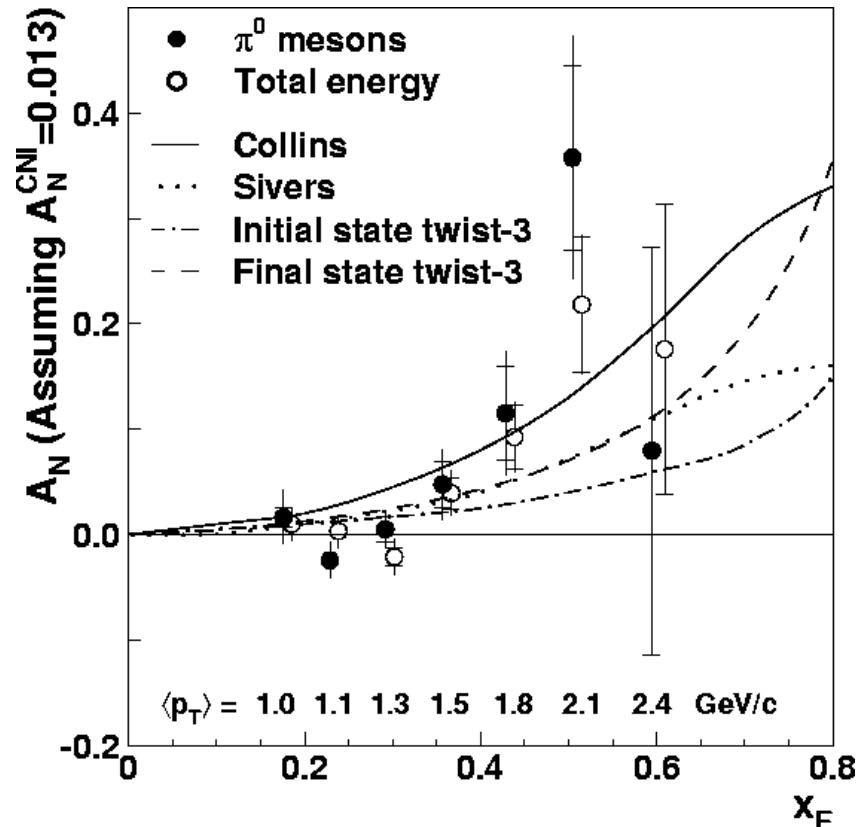
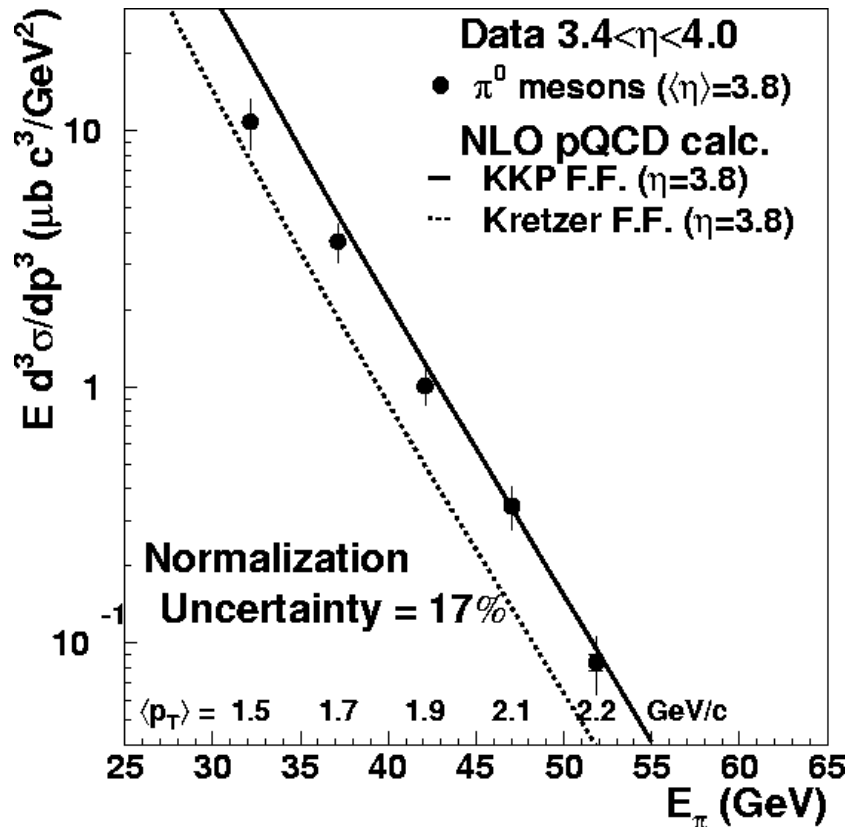
- Precision of relative luminosity monitoring critical: for $A_{LL} \sim 1\%$ $\delta A_{LL}/A_{LL} \sim 5\%$ if $\delta R/R \sim 10^{-3}$
- Luminosity \sim BBC coincidence rate (large cross section of $\sim 27\text{mb}$)
- RHIC stores up to 120 bunches per ring
 - different bunches injected with different spin orientation
 - collision luminosity can vary with spin combination



- relative luminosities calculated for each STAR run, statistical uncertainty $\delta R_{\text{stat}} \sim 10^{-4} - 10^{-3}$
- systematic uncertainty $\delta R_{\text{syst}} < 10^{-3}$

Forward π^0 Production

Run-2 STAR collaboration, PRL **92**, 171801 (2004)



- pQCD calculations consistent with measured large- η π^0 cross sections
- Large transverse single-spin effects observed for $\sqrt{s} = 200 \text{ GeV}$ pp collisions

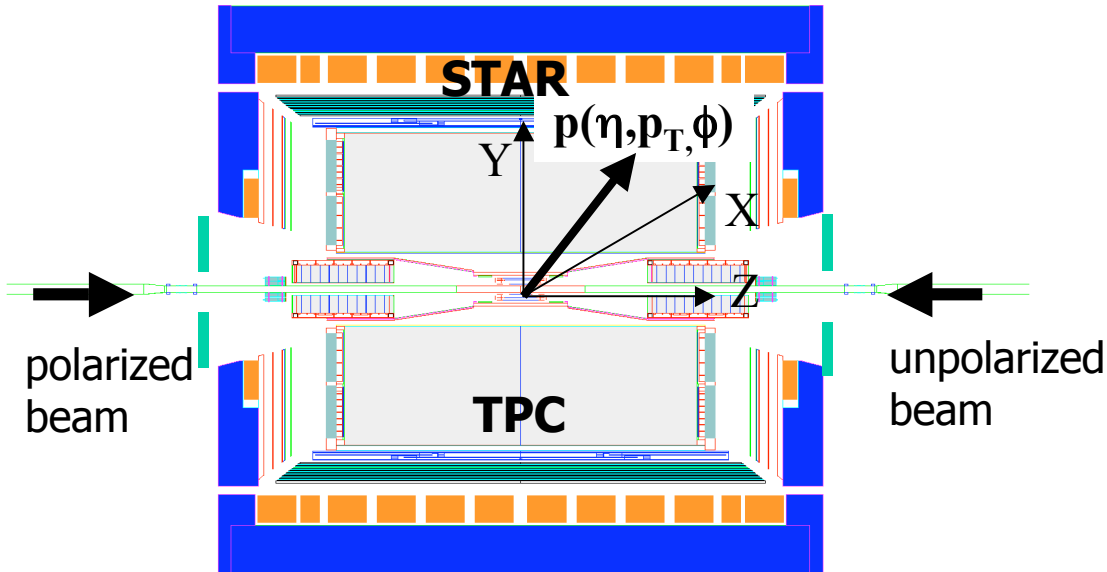
Collins effect \Rightarrow transversity

Sivers effect \Rightarrow orbital angular momentum

Additional measurements required to disentangle contributions



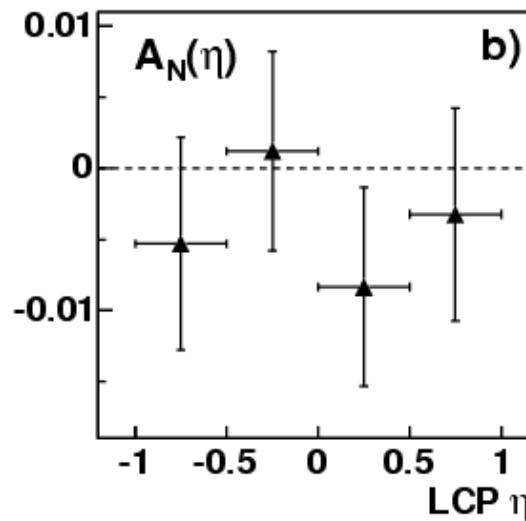
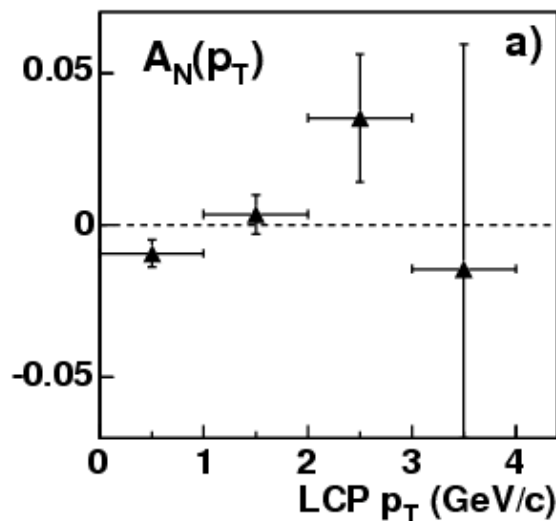
Leading Charged Particle Production at Midrapidity



Leading Charged Particle (LPC) :

- charged particle reconstructed in TPC for $|\eta| < 1.0$ and $\Delta\phi = 2\pi$ with largest p_T $0.4 < p_T < 5 \text{ GeV}$

Run-2 (Preliminary) Results



A_N consistent with 0

- true also for charge separated LCP

BBC Transverse Single Spin Asymmetries

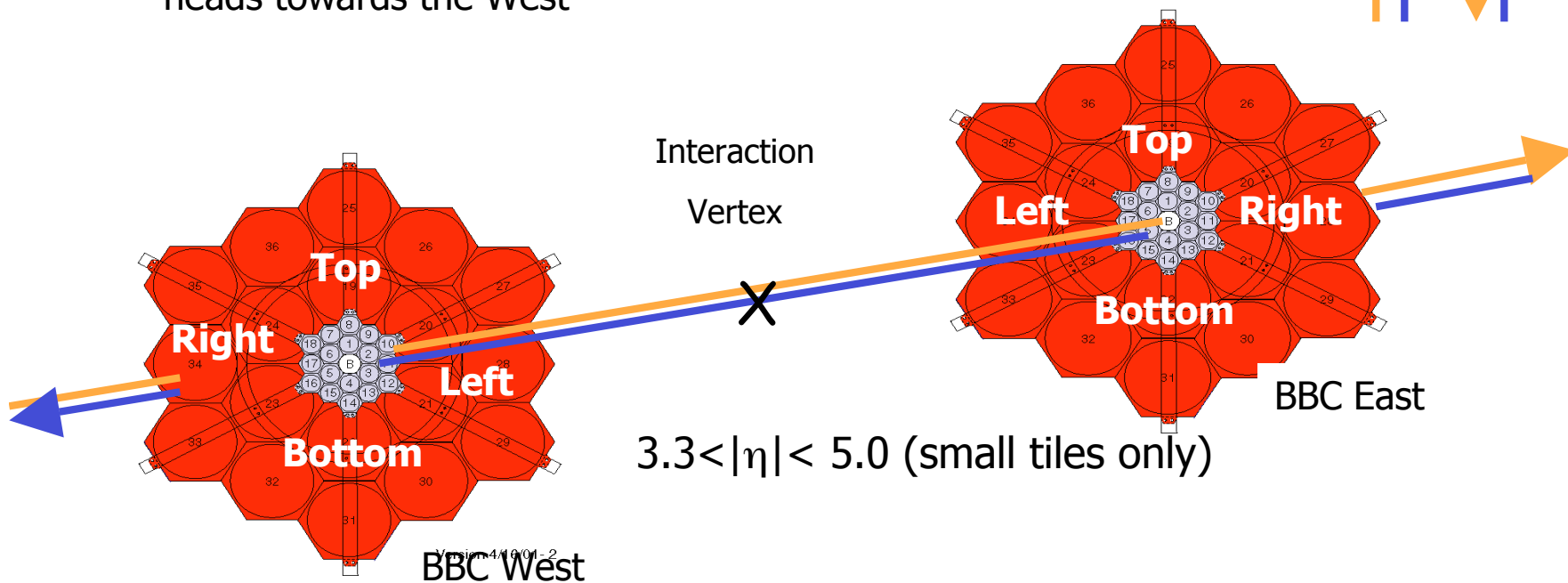
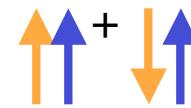
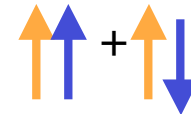
Single spin asymmetries measured for $p+p \rightarrow A + X$, where A – hit(s) in the BBC

$$\varepsilon = P_{\text{beam}} \times A_N \approx \frac{\sqrt{N_L^\uparrow N_R^\downarrow} - \sqrt{N_L^\downarrow N_R^\uparrow}}{\sqrt{N_L^\uparrow N_R^\downarrow} + \sqrt{N_L^\downarrow N_R^\uparrow}}$$

$L(R)$ – number of counts in Left (Right) or Top (Bottom) in the BBC East or BBC West (small annuli) counted every bunch crossing by the scaler system

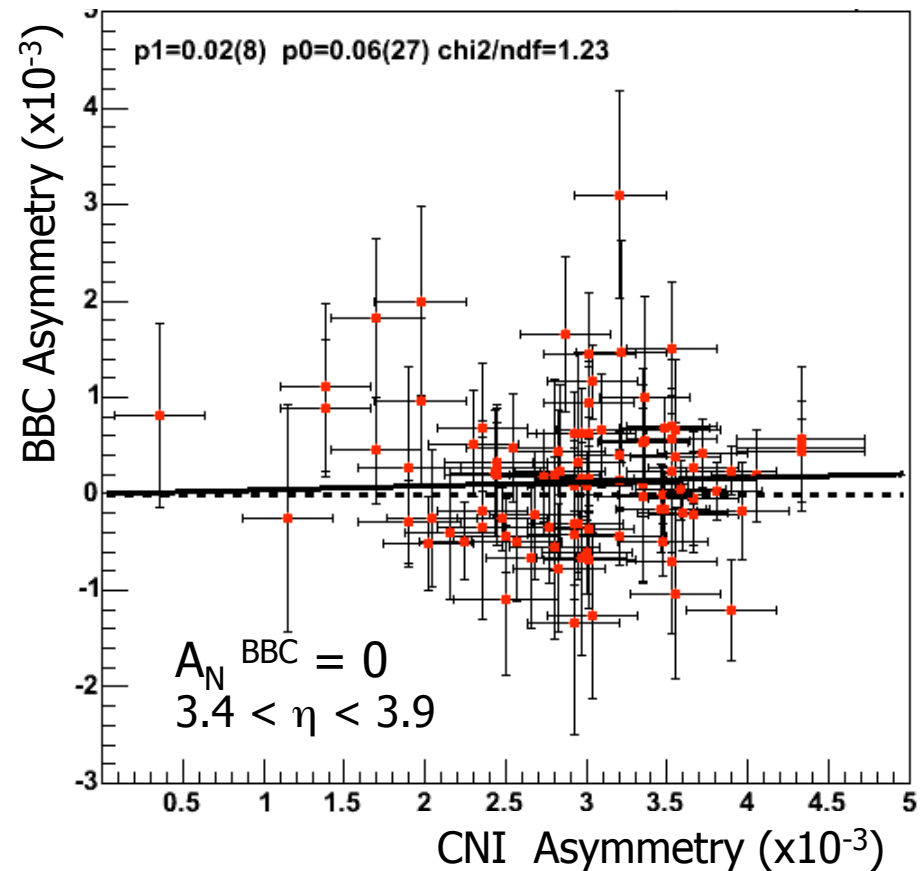
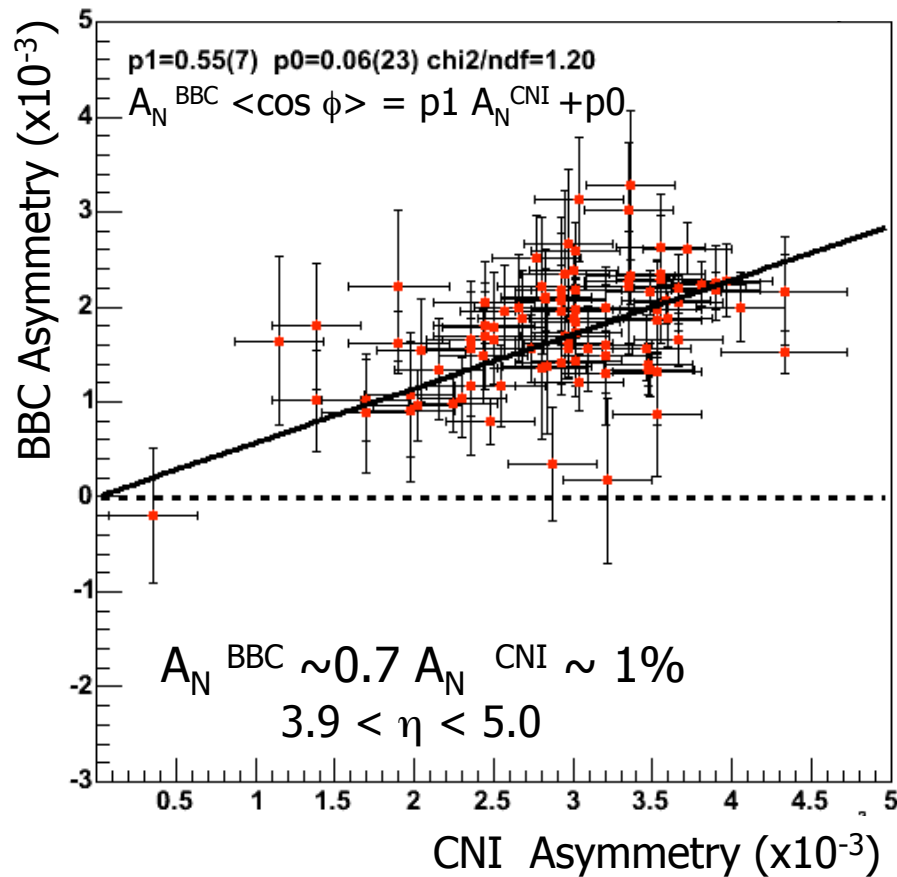
The BBC East and West data sets sorted by beam polarization states:

1. **Polarized Yellow beam** (sum over Blue beam polarization states) heads towards the East
2. **Polarized Blue beam** (sum over Yellow beam polarization states) heads towards the West



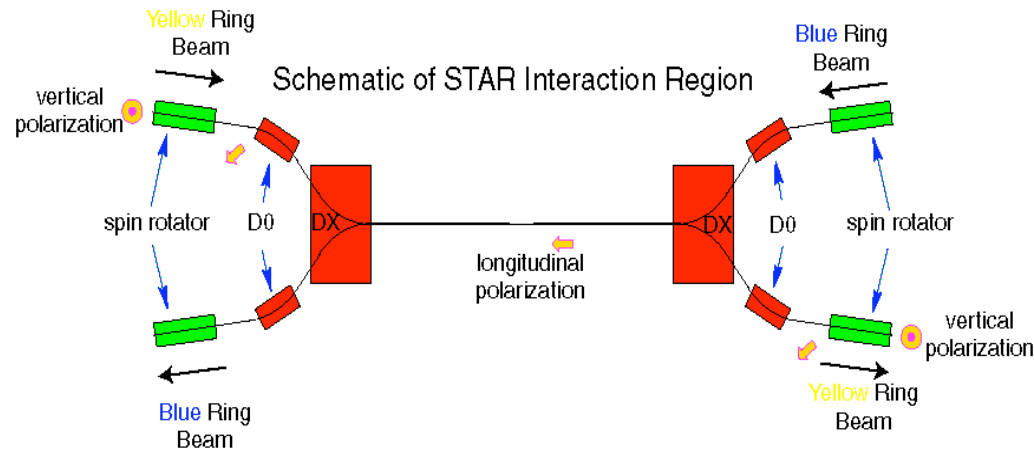


Transverse Single Spin Asymmetries BBC Run-3 (Preliminary) Results



- Unexpected A_N of unknown origin measured with the BBC
- Strong pseudorapidity dependence of A_N for $x_F > 0$ and $A_N = 0$ for $x_F < 0$
- BBC - fast local polarimeter at STAR

How do we get longitudinal polarization?

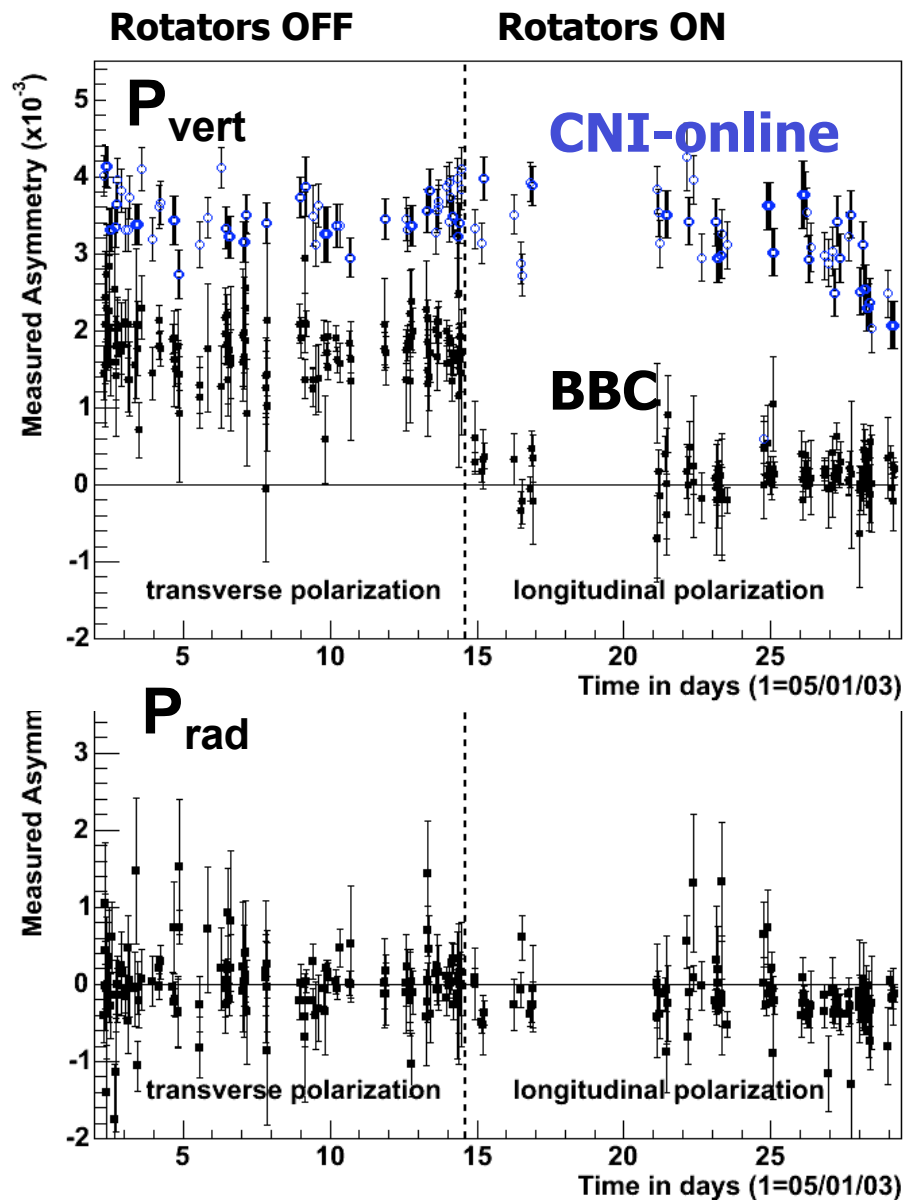


- Stable spin direction at RHIC is vertical
- Spin Rotater brings to almost radial
- D0/DX magnet causes spin precession
- Longitudinal at IR
- DX/D0/Spin Rotater put back to vertical

BBC - local polarimeter at STAR

$\text{asymmetry}_i \sim A_N P_i$ Left-Right asymmetry - sensitive to vertical polarization
 Top-Bottom asymmetry - sensitive to radial polarization

Rotators	OFF	ON
CNI polarimeter	non-zero	non-zero
BBC Left-Right (vertical)	NON_ZERO	ZERO
BBC Top-Bottom (radial)	zero	zero



Beam-Beam Counters

- local polarimeter at STAR

BBC worked very well as a local polarimeter. In Run3 vertical and radial polarizations $< 3\%$

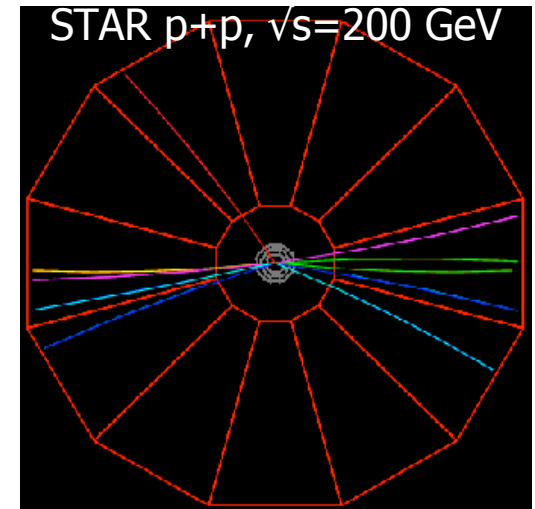
Longitudinal polarization
at STAR -

first step to A_{LL} measurement

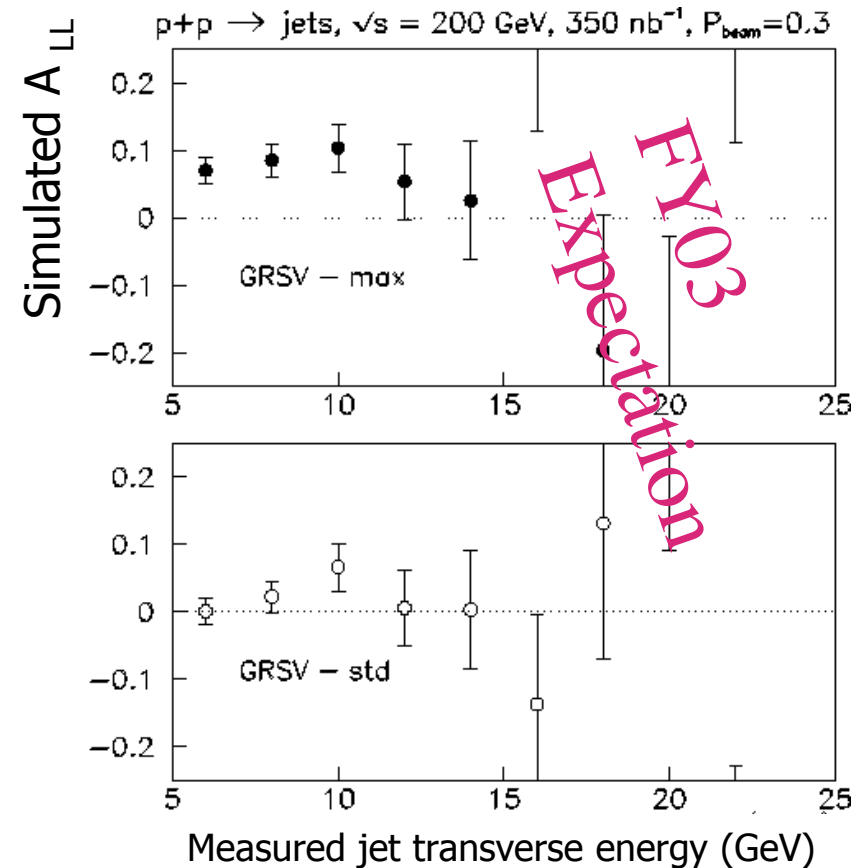
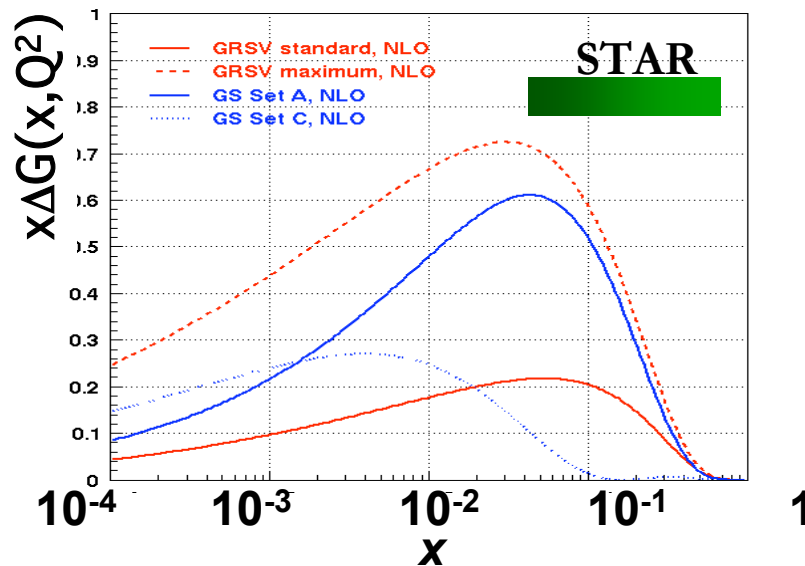
ΔG from inclusive jet production

$$\vec{p} + \vec{p} \rightarrow jet(s) + X \quad \text{at } \sqrt{s} = 200 \text{ GeV}$$

- STAR reconstructs jets via TPC p_T for charged hadrons + EMC E_T for em showers.
- Simulations under approximately realized conditions show sensitivity to ΔG .



$$\begin{aligned}
 gg \rightarrow gg &\propto \frac{\Delta G}{G} \frac{\Delta G}{G} \\
 gq \rightarrow gq &\propto \frac{\Delta q}{q} \frac{\Delta G}{G} \\
 qq \rightarrow qq &\propto \frac{\Delta q}{q} \frac{\Delta q}{q}
 \end{aligned}$$



A 3D visualization of a particle detector barrel, likely the EMC (Electromagnetic Calorimeter) at RHIC. The barrel is represented by a green wireframe grid. Two distinct clusters of high-energy particles, identified as jets, are highlighted with yellow and orange squares. These jets are located on opposite sides of the barrel. A blue circle is drawn around a small cluster of particles at the top of the barrel. The text 'di-Jet Event' is displayed in white at the top center.

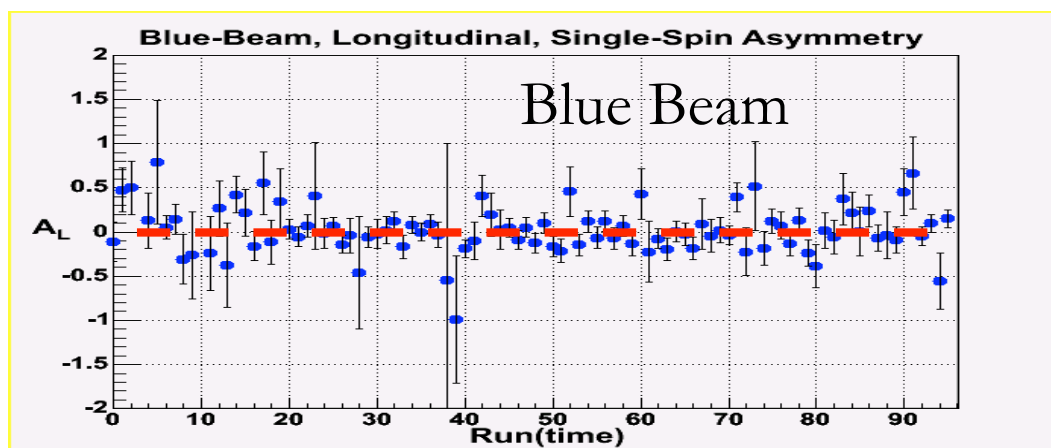
di-Jet Event

Full Barrel EMC - installation completed in 2005

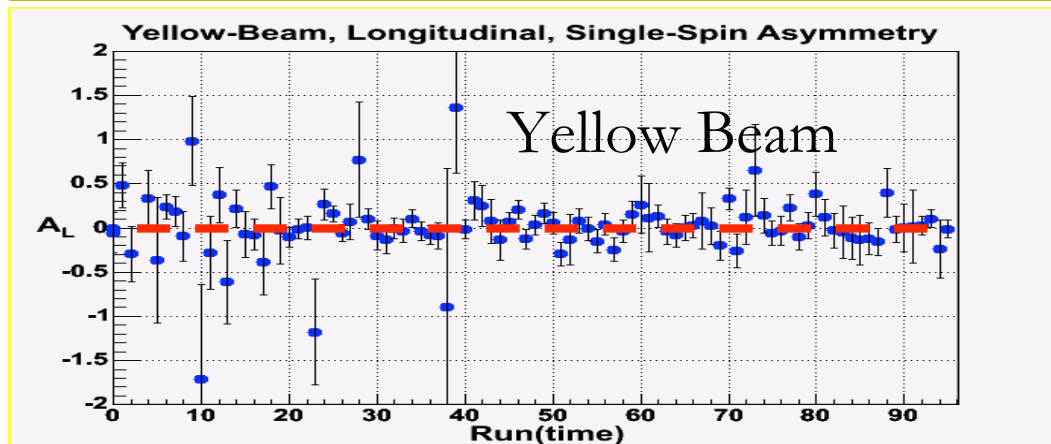
In Run-5 120 modules (4800 towers) + SMD + Preshower

Run-4 data taking with high tower and jet patch triggers using 60 modules of BEMC

Diagnostic Tools: Parity-Violation Single Longitudinal Spin Asymmetries for Inclusive (charged*) Jet Production



$$\langle A_L^B \rangle = 0.001(16)$$
$$\chi^2/\text{dof} = 1.12$$



$$\langle A_L^Y \rangle = 0.022(16)$$
$$\chi^2/\text{dof} = 1.06$$

A_L 's consistent with 0
(as expected)

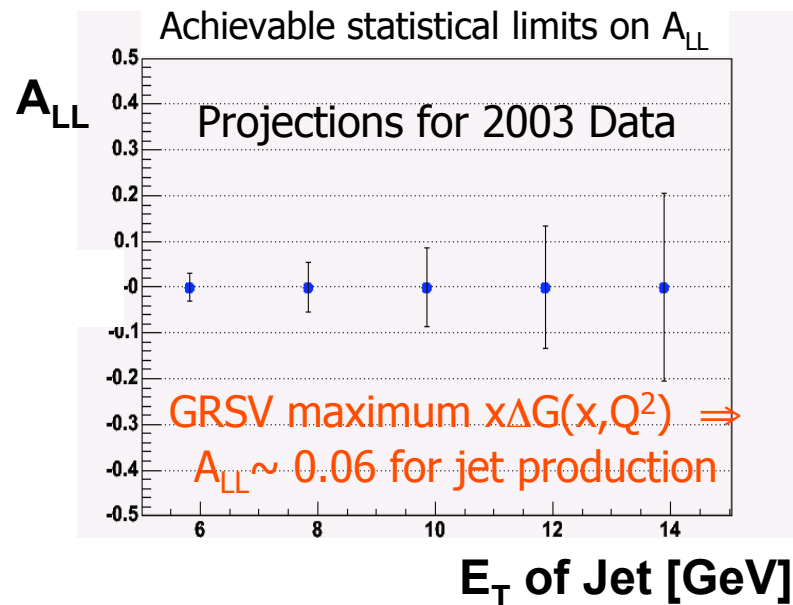
Run Number

*Full jet reconstruction using BEMC waiting final calibration of the calorimeter
- coming soon

Statistical Precision

Achieved in 2003:

- Ave Polarization / Beam ~ 0.25
- RHIC Delivered Integrated Luminosity $\sim 0.4 \text{ pb}^{-1}$



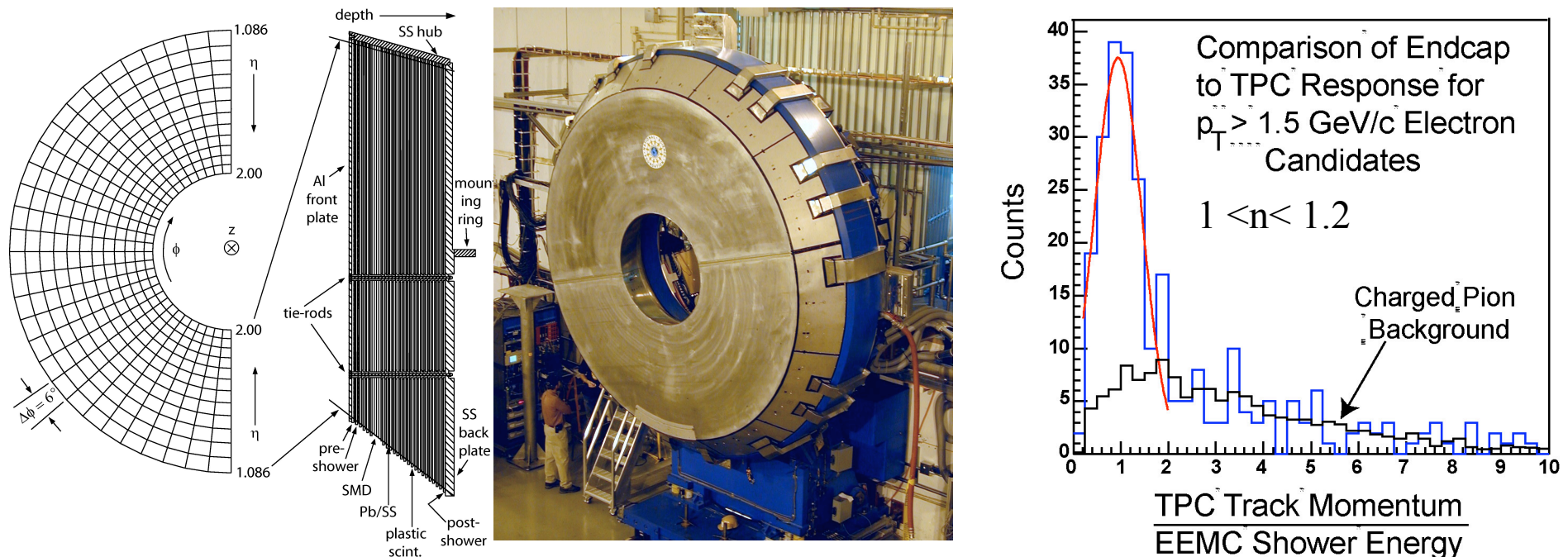
MORE DATA NEEDED

Goal for 2005

- Ave Polarization / Beam ~ 0.40
- RHIC Delivered Integrated Luminosity $\sim 5 \text{ pb}^{-1}$

Endcap Electromagnetic Calorimeter - status of upgrades

- 12 sectors of towers, SMD and Pre- and Post-shower detector installed
- Full electronic readout for all 720 towers, 4 sectors of SMD and Pre/Post (~ 3000 chns)
- 8 remaining sectors of SMD and Pre- and Post-shower electronics will be installed for Y2005



- First EEMC data taking with High Tower trigger (commissioning of jet-patch trigger)
- 4 methods of tower calibration: π^0 mass reconstruction, MIP tracks, electron tracks and from matching slopes of ADC spectra; relative calibration of SMD from cluster finder
- Present analysis - single and di- photons reconstruction

From π^0 and jets heading towards photon physics in forward region (rare probes)

Summary and Outlook

- 1) STAR spin program well under way. Essential equipment/procedures commissioned during 2002-2003: rotators, local polarimetry, accurate relative luminosity monitors; STAR detector upgrades: EMC's, BBC's, FPD.
- 2) Run-2: 1st pp collisions with transversely polarized beams
⇒ single transverse spin asymmetries: $A_N(\pi^0, \text{FPD})$, $A_N(h^{+/-}, \text{TPC})$ and $A_N(\text{BBC})$
- 3) Run-3: 1st pp collisions with longitudinally polarized beams
⇒ BBC worked well as local polarimeter in STAR
⇒ ΔG sensitivity in jet production
- 4) Run-5 goal: ΔG determination from A_{LL} measurements in mid-rapidity jet production and π^0 at $\eta > 1$ (STAR unique!)

Long term plan:

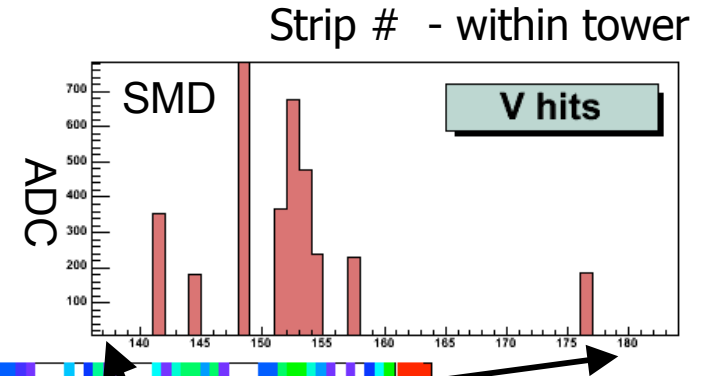
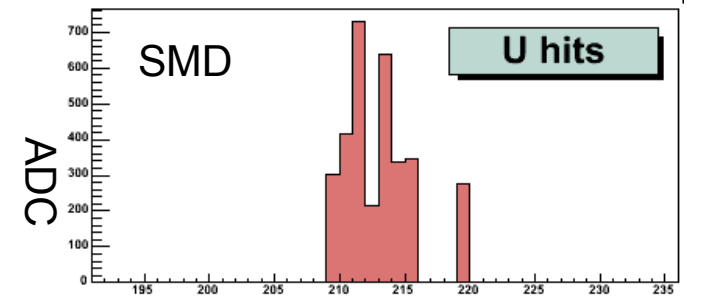
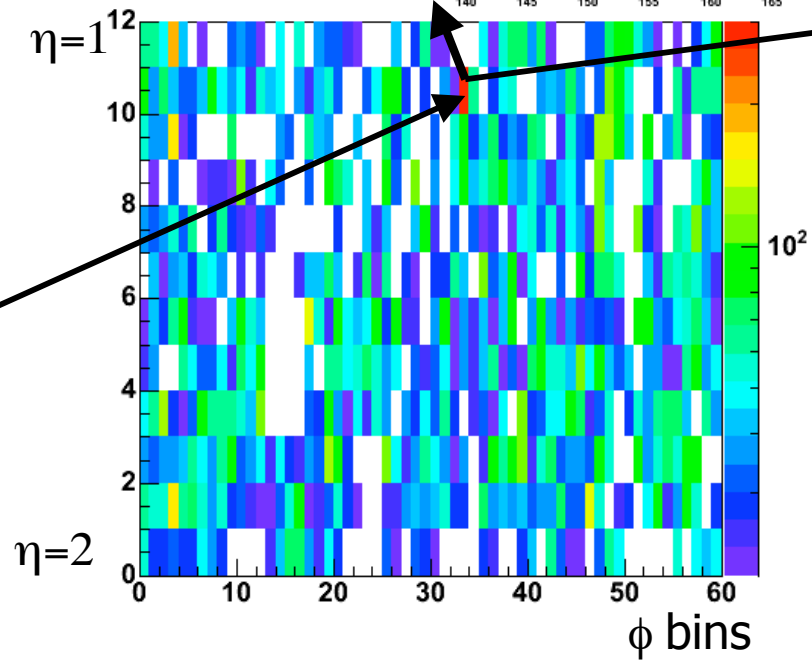
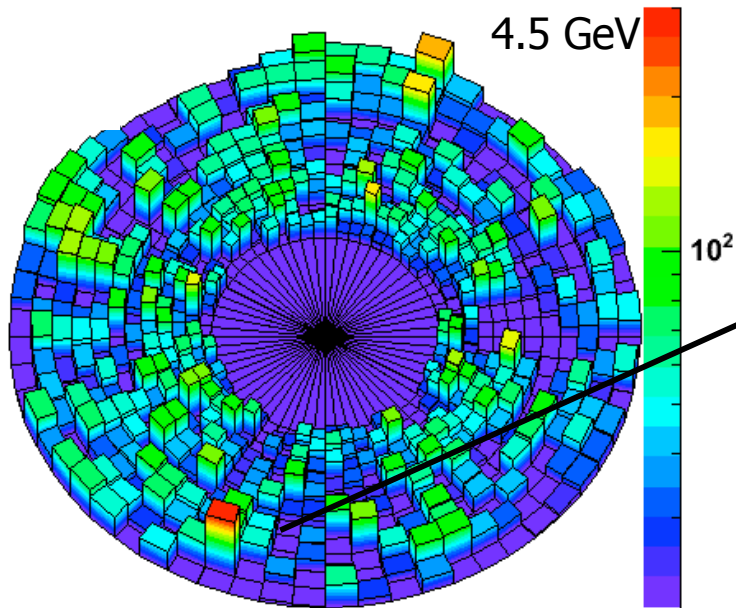
(continuous effort for luminosity and beam polarization development needed)

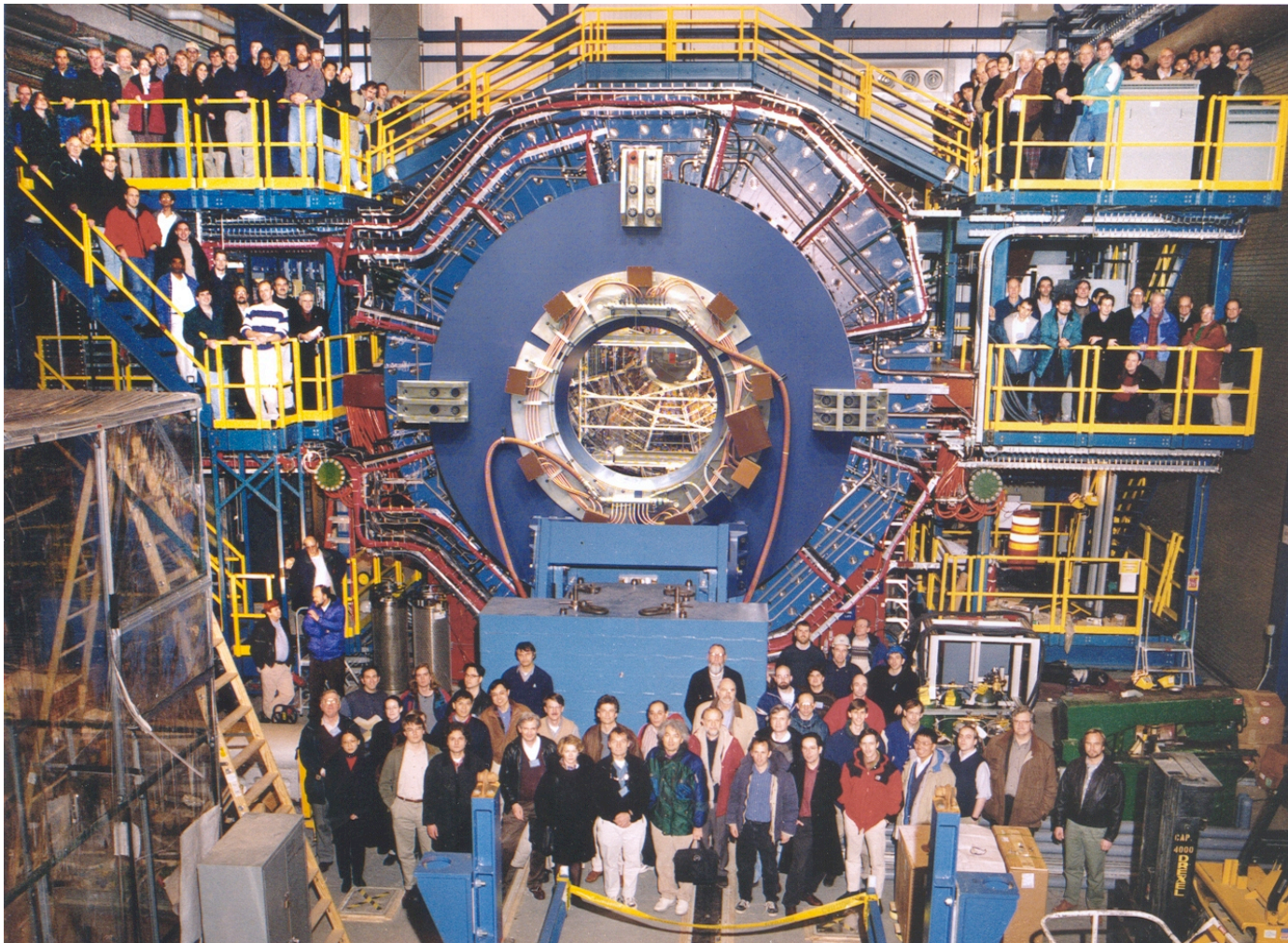
Measurements with rare probes: $A_{LL}(\gamma + \text{jet})$, $A_L^{PV}(W^\pm)$
and transversity via mid-rapidity jet fragmentation

Cluster Finder under Development to start of γ/π^0 reconstruction

Au-Au event from Run-4
(EEMC HighTower trigger)

ADC - pedestal corrected





The **STAR** Collaboration

~ 400 collaborators
 34 institutions
 8 countries

**Strong new
 STAR spin
 interest from:**
*CalTech, LBNL,
 MIT, Valparaiso
 U., Zagreb*

Brazil: Sao Paolo

England: Birmingham

Germany: Frankfurt, MPI - Munich

U.S.: Argonne, Berkeley, Brookhaven National Laboratories

**UC Berkeley, UC Davis, UCLA, Creighton, Carnegie-Mellon, Indiana, Kent State, MSU, CCNY,
 Ohio State, Penn State, Purdue, Rice, Texas, Texas A&M, Washington, Wayne, Yale Univ.**

China: IHEP - Beijing, IPP - Wuhan

France: IReS - Strasbourg, SUBATECH-Nantes

Poland: Warsaw University of Technology

Russia: MEPHI - Moscow, JINR - Dubna, IHEP - Protvino